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PHASE SHIFTER

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(57) Claim

1. An adjustable phase shifter arrangement for selectively varying the relative phase of an RF signal of a given wavelength between at least two radiating elements of an antenna array, adjoining radiating elements being electrically coupled with a respective section of a common conductive strip, said conductive strip being in a predetermined space relationship with a common ground-plane element, said conductive strip having a connection point for connecting a source of RF signal of said given wavelength, said arrangement including a phase shifter element comprising two co-planar fixedly spaced substantially identical planar pieces of dielectric material moveably interposed between at least one said section of said common conductive strip and said common ground-plane element, the length of each said piece being defined by two opposite ends, one end having a first width which is relatively larger than a second width of the other end of said piece with a diminishing width therebetween, wherein the other ends of each said piece are spaced by a distance of approximately one quarter of said given wavelength and said first width is, at least, approximately one quarter of said given wavelength long to form a major end of said phase shifter element having a total width of

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approximately one half of said given wavelength, whereby the phase of RF signal fed to at least one said radiating element can be selectively varied in relation to the phase of the RF signal fed to an adjoining radiating element/s by linearly moving said phase shifter element between a first position corresponding to said other end of said phase shifter element where minimum dielectric material is beneath said conductive strip, and a second position corresponding to said major end of said phase shifter element where maximum dielectric material is beneath said conductive strip.

14. A method of adjusting rhe relative phase of an RF signal of a given wavelength between at least two radiating elements of an antenna array, adjoining radiating elements being electrically coupled with a respective section of a common conductive strip, said conductive strip being in a predetermined spaced relationship with a common ground-plane element, said conductive strip having a connection point for connecting a source of RF signal of said given wavelength, said method comprising the steps of:

A interposing a moveable dielectric phase-shifter element between said section/s of said conductive strip, said dielectric phase shifter element comprising two co-planar fixedly spaced substantially identical planar pieces of dielectric material, the length of each said piece being defined by two opposite ends, one end having a first width which is relatively larger than a second width of the other end of said piece, with a diminishing width therebetween, wherein the other ends of each said piece are spaced by a distance of approximately one quarter of said given wavelength, and said first width is, at least, approximately one quarter of said given wavelength long to form a major end of said phase shifter element having a total width of approximately one half of said given wavelength;

B linearly moving said phase shifter element/s between a first position corresponding to said other end of said phase shifter element where minimum dielectric material is beneath said conductive strip, and a second position corresponding to said major end of said phase shifter element where maximum dielectric material is beneath said conductive strip.

C select a phase shifter element position which provides a desired phase relationship.

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ORIGINAL
COMPLETE SPECIFICATION
STANDARD PATENT

Invention Title:
PHASE SHIFTER

The following statement is a full description of this invention, including the best method of performing it known to us:-

This invention relates to arrangements for changing the orientation or shape of a directional pattern of electromagnetic waves radiated from an aerial system, and in particular to an arrangement for varying the relative phase between two or more radiating elements of an antenna array thereby varying the orientation or shape of the directional pattern of the electromagnetic waves radiated from the antenna array.

Such arrangements are utilised in antenna systems of mobile radiotelephone networks; after such antenna systems are mounted at selected locations it may be required that the downward tilt of the antenna system's radiated electromagnetic wave be adjusted to a desired angle, typically between 0° and 15°.

One known method by which the relative phase between two or more radiating elements can be changed is to change the relative lengths of respective transmission lines connecting the antenna array's common feed point to each element of the antenna array.

Typically, various predetermined lengths of "jumper cables" are provided which are selectively connected between the common feed point and each element to obtain a desired orientation of the directional pattern of the antenna array.

The jumper cables include coaxial connectors to facilitate connection. Furthermore, if stripline is used to connect the common feed point to the respective elements of the antenna array, some form of transition means is required to couple the jumper cable's coaxial connections to the strip line. A disadvantage of this known method is that it is relatively expensive and tedious.

Another known method by which the relative phase between two or more radiating elements can be changed is to change the propagation velocity of the transmission line connecting the common feed point to at least some of the elements of the antenna array. Typically, this latter method is achieved by selectively changing the dielectric constant of the connecting transmission line. If the transmission line is in the form of a conductive strip, the propagation velocity thereof is changed by introducing a dielectric material between the strip and its associated ground-plane.

It is, however, well understood that the introduction of dielectric material

under such a conductive strip causes the strip's normal impedance to be disturbed. For example, if a conductive strip having a certain width and spaced above a ground-plane at a certain distance such as to present a 50 ohm impedance, the introduction of dielectric material between the conductive strip and the ground-plane will reduce the value of this impedance to a value that depends upon the effective dielectric constant of the dielectric material. The resulting impedance mismatch would cause a degradation of return-loss performance of the antenna array.

It is an object of the present invention to provide an adjustable phase shifter arrangement which avoids the abovementioned disadvantages .

It is a further object of the invention to provide an adjustable phase shifter arrangement in which the propagation velocity of a transmission line means connecting a common feed point to at least some of the elements of the antenna array is selectively changed by an adjustable dielectric phase shifter element which does not disturb the normal impedance of the stripline.

According to the invention there is provided an adjustable phase shifter arrangement for selectively varying the relative phase of an RF signal of a given wavelength between at least two radiating elements of an antenna array, adjoining radiating elements being electrically coupled with a respective section of a common conductive strip, said conductive strip being in a predetermined space relationship with a common ground-plane element, said conductive strip having a connection point for connecting a source of RF signal of said given wavelength, said arrangement including a phase shifter element comprising two co-planar fixedly spaced substantially identical planar pieces of dielectric material moveably interposed between at least one said section of said common conductive strip and said common ground-plane element, the length of each said piece being defined by two opposite ends, one end having a first width which is relatively larger than a second width of the other end of said piece with a diminishing width therebetween, wherein the other ends of each said piece are spaced by a distance of approximately one quarter of said given wavelength and said first width is, at least, approximately one quarter of said given wavelength long to form a major end of said phase shifter element having a total width of approximately one half of said given wavelength, whereby the phase of RF

signal fed to at least one said radiating element can be selectively varied in relation to the phase of the RF signal fed to an adjoining radiating element/s by linearly moving said phase shifter element between a first position corresponding to said other end of said phase shifter element where minimum dielectric material is beneath said conductive strip, and a second position corresponding to said major end of said phase shifter element where maximum dielectric material is beneath said conductive strip.

According to a further aspect of the invention there is provided a method of adjusting rhe relative phase of an RF signal of a given wavelength between at least two radiating elements of an antenna array, adjoining radiating elements being electrically coupled with a respective section of a common conductive strip, said conductive strip being in a predetermined spaced relationship with a common ground-plane element, said conductive strip having a connection point for connecting a source of RF signal of said given wavelength, said method comprising the steps of:

A interposing a moveable dielectric phase-shifter element between said section/s of said conductive strip, said dielectric phase shifter element comprising two co-planar fixedly spaced substantially identical planar pieces of dielectric material, the length of each said piece being defined by two opposite ends, one end having a first width which is relatively larger than a second width of the other end of said piece, with a diminishing width therebetween, wherein the other ends of each said piece are spaced by a distance of approximately one quarter of said given wavelength, and said first width is, at least, approximately one quarter of said given wavelength long to form a major end of said phase shifter element having a total width of approximately one half of said given wavelength;

B linearly moving said phase shifter element/s between a first position corresponding to said other end of said phase shifter element where minimum dielectric material is beneath said conductive strip, and a second position corresponding to said major end of said phase shifter element where maximum dielectric material is beneath said conductive strip.

C select a phase shifter element position which provides a desired phase relationship.

In order that the invention may be readily carried into effect, an embodiment thereof will now be described in relation to the drawings, in which:

Figures 1 and 2 are elevation views of a dielectric phase shifter arrangement used to describe the present invention.

Figure 3 is a plan view of a dielectric phase shifter element used in the present invention.

Figure 4 is a schematic representation of an antenna array incorporating the dielectric phase shifter arrangement of the present invention.

Figure 5 is a representation of one side of an antenna system showing the common conductive strip mounted on a ground-plane and the associated adjustable dielectric phase shifter elements.

Figure 6 is the opposite side of the antenna system shown in Figure 5, showing the antenna array.

Figure 7 is a representation of the actuating mechanism of the dielectric phase shifter incorporated in the antenna system shown in Figure 4.

Figure 8 is a representation of a lockable handle arrangement operatively associated with the actuating mechanism shown in Figure 7.

Referring to Figures 1 to 3, the mismatch caused by the introduction of dielectric material under the conductive strip as mentioned above can be eliminated by using quadrature compensation, that is, spacing two mismatches a quarter wavelength apart. As shown in Figure 1, two pieces of dielectric material 1 and 2 spaced one quarter wavelength apart are placed between conductive strip 3 and ground-plane 4 thereby providing a matched phase shifter.

Variation of the width of both pieces 1 and 2 whilst maintaining the one quarter wavelength spacing results in a variation of phase shift without any substantial variation in impedance.

Maximum phase shift occurs when each piece of dielectric material is one quarter wavelength in width, that is, when a total width of one wavelength of dielectric material 5 (Figure 2) is between conductive strip 3 and ground-plane 4.

The degree of phase shift achieved in the conductive strip depends on the dielectric constant of the dielectric material under the conductive strip, though the permittivity will vary depending upon the effects of fringing, air gap etc. For example, a phase shifter having a dielectric of fibre glass has a one wavelength in air of 324 mm at a frequency of 925 MHz. The permittivity of fibre glass is 4.5, but due to the effects of fringing, air gap, etc. when under the conductive strip its effective permittivity is 2.7. Therefore the effective length of one half wavelength at 925 MHz is:

1) $$\frac{324}{2\sqrt{2.7}}=98mm$$

The electrical length in the dielectric is one half wavelength long, which is equivalent to 180°, and the electrical length in air is:

2) $$98x\frac{360}{324}=109^{o}$$

Therefore the additional phase shift introduced by the phase shifter is:

$$180 - 109 = 71°$$

Referring to Figure 3, a phase shifter element 6 which is capable of varying the dielectric constant under a stripline from zero to a maximum value without disturbing the impedance as described above, comprises two substantially identical flat triangular-shaped sections 7 and 8 of dielectric material such as, for example, fibre glass, ceramic or teflon. The apices of sections 7 and 8 are spaced one quarter of a wavelength of a given frequency. The bases of sections 7 and 8 are joined by a linking section 9 whose total width is equal to one half wavelength of the given frequency in the dielectric material chosen. Typically, the thickness of a fibre glass phase shifter 6 is 3 mm, and for a given frequency of 925 MHz the distance between the apices is 81 mm, the length of the link section 9 is 98 mm and the height of each triangular section is approximately 70 mm.

Referring to Figure 4, the antenna array comprises five vertical dipoles 10, 11, 12, 13 and 14 each coupled to a common stripline 15 at terminal points 16, 17, 18, 19 and 20. Conductive strip 15 is fed from one end by a transmission

cable 21 coupled to a source of RF signal. In the sections of the conductive strip coupling adjacent dipoles there is slidably arranged a dielectric phase shifter element 6 described in relation to Figure 3. The dielectric phase shifters 6 are interposed between sections of conductive strip 15 and a common ground-plane element (not shown). By adjusting the position of each dielectric phase shifter element vis-a-vis the conductive strip to vary the dielectric constant, the radiation pattern radiated from the antenna array can be selectively tilted from 0° to 15°.

Referring to Figure 5, common conductive strip 15 in the form of a rectangular cross-section aluminium bar 6 mm x 12 mm is mounted on ground-plane element 22 in a predetermined spaced relationship, for example, 4 mm spacing.

Each dielectric phase shifter element 6 is operatively associated with a rack and pinion mechanism 23, 24, 25 and 26 for providing linear movement to its dielectric phase shifter element. Preferably, the apices of the dielectric phase shifter elements 6 are provided with small extension fingers 27 and 28 to ensure that the dielectric phase shifter element slides freely under the conductive strip and does not jam. Connection to dipole elements 10, 11, 12, 13 and 14 on the opposite side of ground-plane element 22 (see Figure 6) is made to terminal points 16, 17, 18, 19 and 20 on conductive strip 15.

Preferably, in order to maintain an appropriate side-lobe suppression at maximum tilt, amplitude taper may be utilised in a known manner. Moreover, unwanted tilt with frequency can be cancelled by using a known centre feed arrangement in which the transmission cable carrying the RF signal is coupled to the centre dipole thereby dividing the power thrice; one third to the top two dipoles, one third to the centre dipole and one third to the bottom two dipoles. The power to the upper and lower two dipoles can be split unequally between the two upper and two lower dipoles by using transformers integrated into the conductive strip by varying the conductor's width.

Referring to Figures 7 and 8, the rack and pinion mechanism comprises a moveable indented bar 29 to which a dielectric phase shifter element (as shown in Figure 5) is attached, a fixed bar 29a slidably co-operating with indented bar 29, and a pinion 30 operatively engaging the indented bar 29. Pinion 30 is

provided with a shaft 31 to which is attached a lockable handle 32 (Figure 8). Handle 32 is provided with a graduated skirt 33 whose outer perimeter is arranged to co-operate with a locking screw 34. Rotation of handle 32 linearly moves the dielectric phase shifter under conductive strip 15, thereby providiing a simple adjustment of the dielectric constant to influence the propagating velocity of the associated conductive strip section.

The present invention has been described with regard to many particulars, though it will be understood that equivalents may be readily substituted without departing from the scope of the invention.

The claims defining the invention are as follows:

1. An adjustable phase shifter arrangement for selectively varying the relative phase of an RF signal of a given wavelength between at least two radiating elements of an antenna array, adjoining radiating elements being electrically coupled with a respective section of a common conductive strip, said conductive strip being in a predetermined space relationship with a common ground-plane element, said conductive strip having a connection point for connecting a source of RF signal of said given wavelength, said arrangement including a phase shifter element comprising two co-planar fixedly spaced substantially identical planar pieces of dielectric material moveably interposed between at least one said section of said common conductive strip and said common ground-plane element, the length of each said piece being defined by two opposite ends, one end having a first width which is relatively larger than a second width of the other end of said piece with a diminishing width therebetween, wherein the other ends of each said piece are spaced by a distance of approximately one quarter of said given wavelength and said first width is, at least, approximately one quarter of said given wavelength long to form a major end of said phase shifter element having a total width of approximately one half of said given wavelength, whereby the phase of RF signal fed to at least one said radiating element can be selectively varied in relation to the phase of the RF signal fed to an adjoining radiating element/s by linearly moving said phase shifter element between a first position corresponding to said other end of said phase shifter element where minimum dielectric material is beneath said conductive strip, and a second position corresponding to said major end of said phase shifter element where maximum dielectric material is beneath said conductive strip.

2. An arrangement as claimed in claim 1, wherein each of said substantially identical planar pieces is triangular-shaped, said one end being the base of the triangular-shaped piece and the other end being the apex of the triangular-shaped piece.

3. An arrangement as claimed in claim 1 or 2, wherein said identical planar pieces are joined proximate said one end such as to form an integral phase shifter element.

4. An arrangement as claimed in claim 3, wherein said substantially identical planar pieces are joined by an integral linking member whose width is substantially the same as the width of said major end of said phase shifter element.

5. An arrangement as claimed in any one of the preceding claims, wherein the total width of said major end of said phase shifter element equals

$$\frac{\lambda}{2\sqrt{\epsilon_r}}$$

where λ is one wavelength in air of a given thickness of the dielectric material of the phase shifter element at a given frequency; and ϵ_r is the effective permittivity of the dielectric material of the said phase shifter element.

6. An arrangement as claimed in any one of the preceding claims, including actuating means arranged to linearly move in a selective manner said phase shifter element/s between said first position and said second position.

7. An arrangement as claimed in claim 6, as appended to claims 1 to 3, wherein said actuating means comprises at least one rack and pinion arrangement, said rack/s being attached to said major end of said phase shifter element/s.

8. An arrangement as claimed in claim 6, as appended to claims 4 or 5, wherein said actuating means comprises at least one rack and pinion arrangement, said rack/s being attached to said integral linking member.

9. An arrangement as claimed in claim 7 or 8, wherein said pinion/s is/are attached to respective handle means for adjusting by rotational movement the said phase shifter element/s position.

10. An arrangement as claimed in claim 9, wherein said handle means is operatively associated with a graduated skirt whose outer perimeter is arranged to co-operate with a locking screw to lock an adjusted phase shifter element in position.

11. An arrangement as claimed in any one of the preceding claims, wherein at least one of said sections of the common conductive strip includes transformer means arranged to provide a predetermined amplitude taper.

12. An arrangement as claimed in claim 11, wherein said connection point for connecting a source of RF signal is a point in the centre of said common

conductive strip.

13. An arrangement as claimed in any one of the preceding claims, wherein said conductive strip is an aluminium bar of rectangular cross-section.

14. A method of adjusting rhe relative phase of an RF signal of a given wavelength between at least two radiating elements of an antenna array, adjoining radiating elements being electrically coupled with a respective section of a common conductive strip, said conductive strip being in a predetermined spaced relationship with a common ground-plane element, said conductive strip having a connection point for connecting a source of RF signal of said given wavelength, said method comprising the steps of:

A interposing a moveable dielectric phase-shifter element between said section/s of said conductive strip, said dielectric phase shifter element comprising two co-planar fixedly spaced substantially identical planar pieces of dielectric material, the length of each said piece being defined by two opposite ends, one end having a first width which is relatively larger than a second width of the other end of said piece, with a diminishing width therebetween, wherein the other ends of each said piece are spaced by a distance of approximately one quarter of said given wavelength, and said first width is, at least, approximately one quarter of said given wavelength long to form a major end of said phase shifter element having a total width of approximately one half of said given wavelength;

B linearly moving said phase shifter element/s between a first position corresponding to said other end of said phase shifter element where minimum dielectric material is beneath said conductive strip, and a second position corresponding to said major end of said phase shifter element where maximum dielectric material is beneath said conductive strip.

C select a phase shifter element position which provides a desired phase relationship.

15. A method as claimed in claim 14, wherein the total width of said major end of said phase shifter element equals:

$$\frac{\lambda}{2\sqrt{\epsilon_r}}$$

where λ is one wavelength in air of a given thickness of the dielectric material of the phase shifter element at the given frequency; and ϵ_r is the effective permittivity of said dielectric material of the said phase shifter element.

16. A method as claimed in claim 14 or 15, wherein the desired phase relationship is one which produces a desired directional pattern of electromagnetic waves radiated at said given frequency from said antenna array.

17. A method as claimed in claim 16, wherein the desired directional pattern is a vertical pattern radiated at a desired angle.

18. An adjustable phase shifter arrangement substantially as herein described with reference to Figures 1 to 8 of the accompanying drawings.

19. A method of adjusting the relative phase of an RF signal of a given wavelength, substantially as herein described with reference to Figures 1 - 8 of the accompanying drawings.

20. An antenna array for a mobile radiotelephone network, incorporating an adjustable phase shifter arrangement as claimed in any one of claims 1 to 13 and claim 18.

DATED THIS FIFTEENTH DAY OF SEPTEMBER 1995
RADIO FREQUENCY SYSTEMS PTY. LIMITED

ABSTRACT

An adjustable phase shifter arrangement for varying the relative phase of an RF signal between at least two radiating elements of an antenna array and thereby alter the angle of the antenna array's radiation pattern. The arrangement comprises one or more dielectric phase shifter elements (6) moveably interposed between a conductive strip 15 commonly coupling radiating elements (10, 11, 12, 13 and 14) and a common ground plane (22). By linearly moving the phase shifter element/s which are of a characteristic shape and dimension, the dielectric constant beneath the conductive strip can be varied without disturbing the conductive strip's normal impedance.

FIGURES 5 and 6

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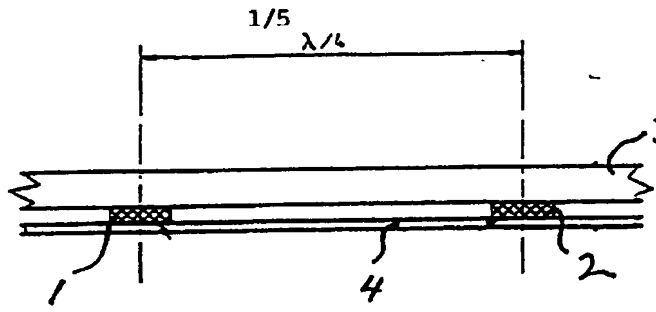

Fig 1

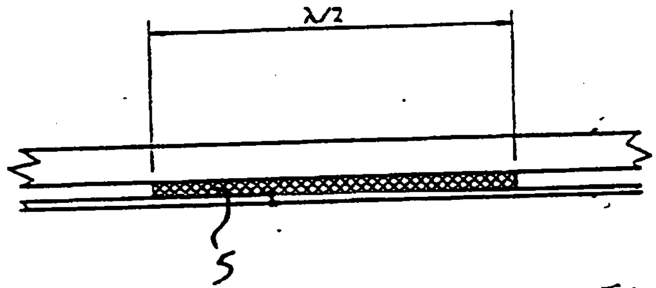

Fig 2

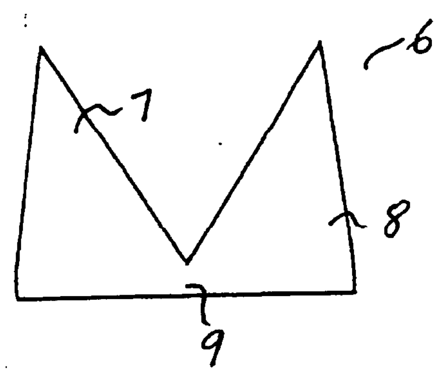

Fig 3

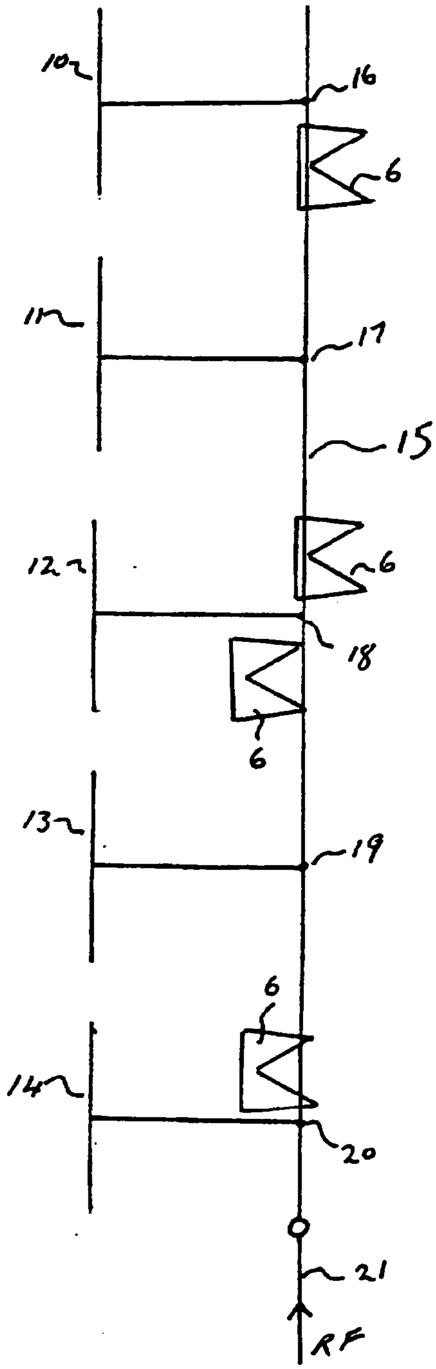

Fig 4

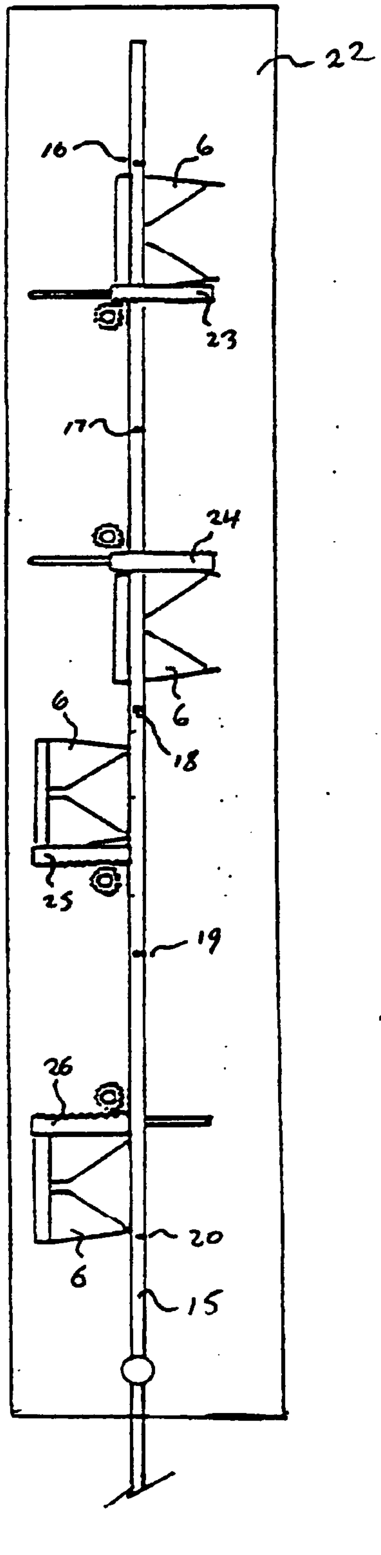

Fig 5

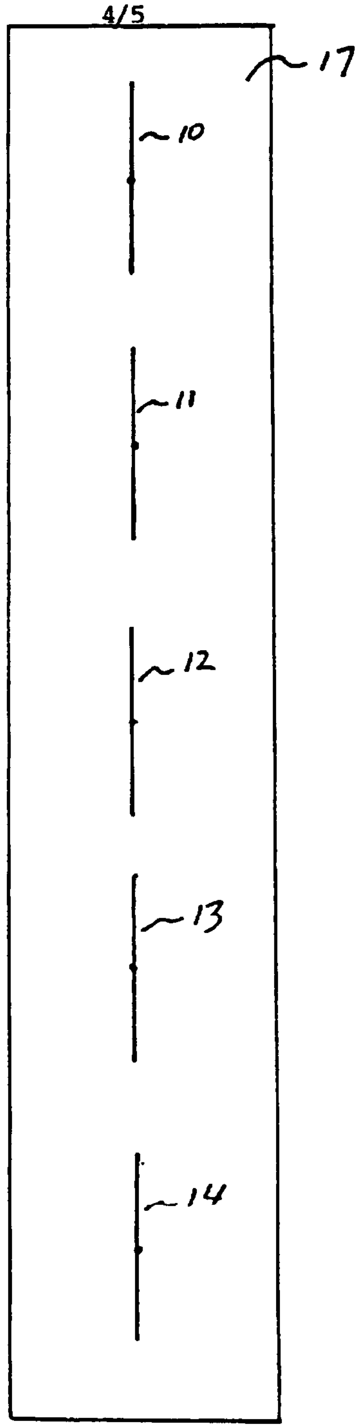

Fig 6

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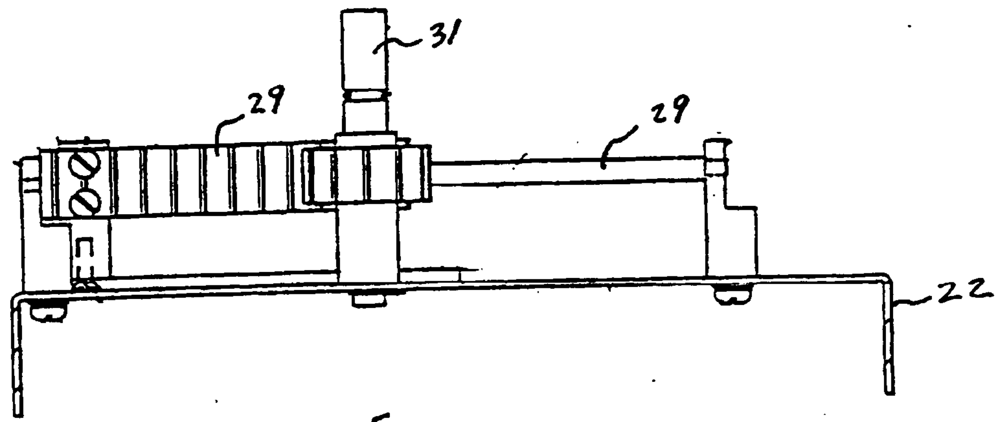

Fig 7

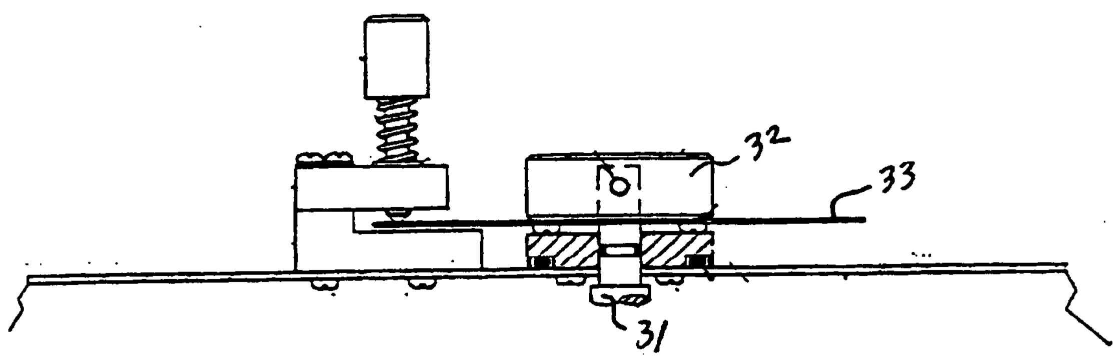

Fig 8